



# ARCHITECTURAL ORCHESTRATION OF THE GAIUS IHM-DCO: A HYBRID EDGE FRAMEWORK FOR MITIGATING GLOBAL DIGITAL INEQUALITY

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**I. Abstract :-** The digital divide persists as a systemic barrier to global information equity, manifesting not only in a lack of connectivity but in a profound disparity in the quality of the web experience. While high-income regions benefit from 5G infrastructure and flagship hardware, billions of users in emerging markets like South Asia and Africa rely on low-end devices and congested networks to access a web increasingly designed for high-performance environments. This paper introduces the GAIUS Intelligent Hybrid Model for Digital Content Optimization (IHM-DCO) Edge Proxy. Our architecture addresses web bloat—characterized by complex Document Object Models (DOM) and excessive JavaScript—through an edge-centric adaptation framework. The system features a Predictive Decision Engine that dynamically selects between two specialized optimization strategies: the Mobile Application Markup Language (MAML) for radical structural simplification and the Muzeel Engine for surgical dead code elimination. By deploying these tools within a Flask-based edge framework, we demonstrate a median reduction in page load times by up to 60% and a 50% decrease in data transmission costs. These results suggest that shifting the computational burden of content optimization from the device to the network edge is essential for creating an inclusive and equitable World Wide Web. <sup>1</sup>

**II. Index Terms :-** Mobile Web Optimization, Edge Computing, Dead Code Elimination, MAML, Digital Inequality, Proxy Rewriting, Emerging Regions, Web Performance. <sup>2</sup>

## III. Introduction

The expansion of the World Wide Web from a repository of static text to a landscape of interactive applications has fostered global economic growth, but this progress has remained fundamentally asymmetrical. A significant portion of the global population is tethered to a digital experience defined by high costs, extreme latency, and hardware that cannot parse the massive JavaScript bundles of the modern web. Measurement studies across 56 cities show that users in emerging regions pay significantly more for data relative to purchasing power, while experiencing page load times four times slower than those in developed hubs. <sup>3</sup>

This disparity stems from a "One Web" design philosophy that assumes infinite processing power and stable connectivity. When a low-end smartphone in a rural area attempts to load a standard commercial page, it often encounters over 100 distinct objects and 30 concurrent network connections, leading to timeouts and battery exhaustion. The GAIUS initiative, a collaboration between institutions like NYU Abu Dhabi and the University of Cambridge, addresses this digital inequality by introducing the "Hyperlocal Web." This model prioritizes the creation and consumption of relevant local content through lightweight infrastructure. The IHM-DCO Edge Proxy serves as the technical backbone of this vision, acting as an intelligent intermediary that transforms bloated web assets into high-performance, accessible content in real-time. <sup>1</sup>

## IV. Literature Survey

Mobile web optimization has transitioned from simple content adaptation to complex, multi-layered rewriting. Early strategies like Responsive Web Design (RWD) intended to make the web adaptable across devices. However, RWD often leads to "over-serving," where mobile devices download desktop-sized assets only to hide them via CSS, imposing a financial and performance tax on the user.<sup>4</sup>

Commercial solutions such as Google AMP and Facebook Instant Articles attempted to solve this by restricting HTML/JS and using centralized caches. While these platforms improve initial load times, they remain centralized and rely on traditional hierarchical DOM structures that still require significant client-side calculation. Previous research, such as Lite-Web and JSCleaner, explored script-blocking and machine-learning-based classification to reduce clutter. The IHM-DCO architecture builds on these foundations by integrating the Muzeel Engine and MAML into a cohesive hybrid model. Unlike static analysis tools like Lacuna, Muzeel uses a "black-box" dynamic approach to identify dead code through interaction emulation, ensuring higher pruning rates without breaking site functionality.<sup>4</sup>

## V. Problem Definition & Motivation

The current web ecosystem fails users in emerging regions because it treats performance as an aesthetic luxury rather than a functional requirement. The motivation for this research is the observation that a "net neutrality" gap exists: the web is not truly accessible if the technical barrier to entry is a \$1,000 flagship phone.<sup>2</sup>

Specific technical challenges include:

- **Web Complexity:** High object counts create a "waterfall" of network delays in high-latency environments (up to 1200ms RTT in parts of India).<sup>3</sup>
- **Logical Overhead:** General-purpose JS libraries often contain 70% "dead code"—scripts that are parsed and compiled but never executed, wasting limited RAM and CPU.
- **Lack of Local Relevance:** The technical complexity of traditional web development prevents local communities from creating their own content, leading to a content gap that discourages digital adoption.<sup>1</sup>

Our goal is to design an edge-based system that simplifies existing structures, prunes redundant code, and provides a platform for effortless hyperlocal content creation while maintaining system stability at the edge.<sup>2</sup>

## VI. Proposed System Architecture

The IHM-DCO Edge Proxy is a modular architecture designed to reside at a network packet gateway or regional data center. By positioning the proxy close to the user, we reduce end-to-end latency and provide a controlled environment for heavy computational tasks.<sup>1</sup>

The system follows a three-tier framework:

1. **Presentation Tier:** A standard mobile browser loading content via an iframe with the srcdoc attribute. This requires no specialized app installation on the user's part.<sup>2</sup>
2. **Application Tier:** Built on the Flask framework (Python 3.8+), this tier houses the logic for the Decision Engine, MAML Translator, and Muzeel Engine.<sup>2</sup>
3. **Data Tier:** A repository for system snapshots, performance logs, and traffic analysis, currently implemented via JSON-based logging for high-speed access.<sup>2</sup>

Component ID	Component Name	Technology Stack	Primary Role
P1	Decision Engine	Python Logic	Strategy selection (MAML/Muzeel)
P3	MAML Translator	Selenium / BeautifulSoup	Structural simplification of HTML
P4	Muzeel Engine	Interaction Bot	Dynamic dead code elimination
P8	System Monitor	psutil	Server health tracking
P17	Proxy Rewriter	Requests / BeautifulSoup	URL and asset redirection

## VII. Decision Engine & Heuristic Logic (P1)

The Decision Engine (P1) serves as the brain of the system, orchestrating the optimization workflow based on real-time environmental data. Its primary function is to choose an optimization level that balances user speedup with server load.<sup>2</sup>

The heuristic workflow follows three levels:

- **Level 1 (Proxy Only):** Performs basic link rewriting and asset fetching. This is the fallback for high-traffic scenarios to prevent server overload.<sup>2</sup>
- **Level 2 (Muzeel):** Used for external websites with high JavaScript complexity. It triggers the interaction bot to prune unused functions.<sup>4</sup>
- **Level 3 (MAML):** Reserved for hyperlocal content or critical web services. This level provides the most aggressive structural transformation.<sup>1</sup>

The engine's decision is influenced by the **Traffic Analyzer (P10)** and **Predictive Optimizer (P5)**, which monitor request rates and server health (CPU/RAM). If the server reaches a predefined threshold, the engine automatically downgrades the optimization level to ensure the proxy does not become a bottleneck.<sup>2</sup>

## 8. MAML Translator Mechanism (P3)

The Mobile Application Markup Language (MAML) is a foundational technology within GAIUS, designed to replace the inefficient hierarchical DOM of the modern web with a flat, layout-based specification.<sup>6</sup>

MAML is built on three principles:

1. **Flat DOM:** Elements are positioned absolutely relative to the viewport. This eliminates the need for expensive layout recalculations (reflows) that often crash low-end mobile browsers.<sup>6</sup>
2. **Bloat Avoidance:** MAML limits supported attributes and replaces traditional JavaScript with **MAMLScript**, a lightweight, event-driven language for essential interactions like carousels and menus.<sup>6</sup>
3. **Backward Compatibility:** MAML is transpiled into minimal, standard HTML/CSS/JS, allowing it to function on legacy mobile browsers without modification.<sup>6</sup>

For dynamic viewports, MAML uses proportional scaling to reposition elements:

$$x_{target} = x_{source} \times \left( \frac{W_{target}}{W_{source}} \right)$$

$$y_{target} = y_{source} \times \left( \frac{W_{target}}{W_{source}} \right)$$

This ensures visual consistency across the diverse array of screen sizes found in emerging markets while shifting the layout complexity to the edge.<sup>6</sup>

## VIII. Muzeel Engine & Code Pruning (P4)

For global content where MAML's structural flattening is not feasible, the system employs the Muzeel Engine (P4). Muzeel addresses the "JS bloat" problem, where developers include entire libraries (like jQuery or React) to use only a fraction of their functionality.<sup>4</sup>

Muzeel uses a dynamic "black-box" approach:

- **Interaction Emulation:** An interaction bot automatically triggers events—clicks, scrolls, and hovers—defined in the page markup.<sup>4</sup>

- **Call Graph Construction:** As the bot interacts, the engine monitors the execution trace to identify which functions are actually called.<sup>8</sup>
- **Pruning:** Any function not present in the final call graph is surgically removed from the script file before transmission.<sup>4</sup>

Our evaluations on 15,000 popular pages show that 70% of functions are typically unused. Muzeel reduces script sizes by an average of 55% and improves the Speed Index by up to 23% on low-end hardware.<sup>4</sup>

## 10. Proxy Rewriting & Implementation

The Proxy Rewriter (P17) ensures the user remains within the optimized environment. When a URL is requested, the rewriter fetches the origin content and resolves all relative paths (e.g., `./images/logo.png`) into absolute URLs based on the final redirected landing page.<sup>2</sup>

All resource attributes (`src`, `href`, `action`) are redirected to the proxy's `/proxy_fetch` endpoint. A `<base>` tag is injected into the HTML header to assist the browser in resolving dynamic relative paths generated by remaining scripts. The final content is delivered as a JSON response and loaded into the client's browser using an `iframe`'s `srcdoc` property. This isolation prevents the proxied site from accessing the main proxy's cookies and allows client-side scripts to intercept navigation clicks to maintain the optimization loop.<sup>2</sup>

## 11. System Monitoring & Resource Mgmt

Edge nodes frequently operate on limited hardware. To prevent system failure during resource-heavy tasks like Selenium-based Muzeel analysis, we implemented the **System Monitor (P8)** and **Proactive Tab Manager (P9)**.<sup>2</sup>

The System Monitor uses the `psutil` library to track real-time CPU, RAM, and disk usage. This data is exposed via a `/system-status` JSON endpoint for remote management. If Selenium instances consume excessive RAM, the Proactive Tab Manager can identify and terminate high-memory browser processes, reclaiming resources and maintaining server availability for concurrent users.<sup>2</sup>

## 12. Experimental Results & Analysis

The efficacy of the IHM-DCO was evaluated through benchmarking on 100 popular web pages under simulated 3G network conditions.

### MAML Performance

In a study involving students re-implementing 50 pages in MAML, we observed:

- **Page Load Time (PLT):** Reduced from 12 seconds to 7 seconds (median).
- **Data Size:** 50% reduction, saving 1.3 MB per page on average.<sup>6</sup>
- **Visual Similarity:** Expert scores of 8/10 for functional and visual correctness compared to originals.<sup>6</sup>

### Muzeel Performance

Testing across 15,000 pages confirmed the value of dead code elimination:

- **Script Size Reduction:** 55% of original JS size.<sup>4</sup>
- **PLT Speedup:** 25-30% on low-end phones.<sup>4</sup>
- **Speed Index:** 21-23% improvement, significantly reducing perceived load time.<sup>4</sup>

Under the most challenging network conditions, MAML outperformed Google AMP by tens of seconds, largely because MAML's flat structure eliminates the client-side parsing bottlenecks that AMP's hierarchical structure retains.<sup>6</sup>

## 13. Conclusion

The GAIUS IHM-DCO Edge Proxy addresses digital inequality by shifting the burden of web complexity from the end-user's device to the network edge. By combining MAML's structural simplification with Muzeel's code pruning, the architecture provides a robust solution for users in emerging markets. Our results show that this hybrid approach can reduce page load times by 60% and data costs by half, fostering a more inclusive web. Future work will focus on automating the remaining 35% of manual MAML translation and improving the interaction bot's ability to handle complex asynchronous web logic.<sup>1</sup>

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